vestigators. Similarly, our filling experiments should correspond to the "normal" filling process.

Allen and Matheson[6] have interpreted their results by assuming that there are two types of films, "thick" films formed by the plunging procedure and "normal" films. The present experiments suggest that such an assumption may not be necessary, but rather that changes in the profile $\mu_f(s)$ and a redistribution of the vorticity production areas in the film are responsible for switching the rates. This viewpoint is consistent with recent observations made by us on the isothermal flow of He II through narrow slits.[7] When the liquid was driven by a gravitational head such that throughout the experiment $\vec{v}_s > \vec{v}_{s,c}$, the pressure difference ΔP, and hence $\Delta\mu$ also, was shown to be equally distributed (statistically) over the entire length of the slit. In this case the reproducible flow rates obtained were consistently lower than when the fluid was driven with a plunger beginning with $\vec{v}_s < \vec{v}_{s,c}$. In the forced-flow experiments, it appeared as if vorticity was preferentially produced at certain sites not uniformly distributed along the channel.

The probings reported here serve to illuminate some of the gross features of film flow. Further studies are in progress with multiple probes in order to define $\mu_f(s)$ more completely in various geometries and, in particular, to investigate to what additional extent changes in R are accompanied by changes in the chemical potential profile.

The authors are indebted, of course, to Dr. B. D. Josephson for his original comments, and as well to Dr. E. Huggins for stimulating discussions, and to Mr. A. P. Roensch for his painstaking and ingenious glass blowing.

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[1] See, for example, K. R. Atkins, Liquid Helium (Cambridge University Press, Cambridge, England, 1959), Chap. 7.

[2] The ingenious double beaker experiment [J. Daunt and K. Mendelssohn, Phys. Rev. 69, 126 (1946); B. S. Chandrasekhar and K. Mendelssohn, Proc. Phys. Soc. (London) A68, 857 (1955)], represents a type of potentiometer which has shown that in the film, mass motion may take place under zero potential. Our objective in the present paper is quite different, since we wish to study nonzero potentials as well. Whereas this has not previously been accomplished for the film, R. Bowers and K. Mendelssohn [Proc. Phys. Soc. (London) A63, 178 (1950)] and R. Bowers, B. S. Chandrasekhar, and K. Mendelssohn [Phys. Rev. 80, 856 (1950)] have reported pressure measurements along the flow path of He II through narrow channels.

[3] See, for example, P. W. Anderson, Rev. Mod. Phys. 38, 298 (1966).

[4] The chemical potential $\mu(\vec{v})$ of the moving film has been shown [J. Tilley, Proc. Phys. Soc. (London) 84, 77 (1963)] to be given by $\mu(\vec{v}) = \mu(0) - (\rho_n/2\rho)(\vec{v}_n - \vec{v}_s)^2$, where $\mu(0)$ refers to the chemical potential of the film at rest and $\vec{v}_n$ is the normal fluid velocity assumed to be zero. The probes described here are not influenced by the velocity term but measure only $\mu(0)$.

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HYPERFINE FIELD SPECTRA IN Fe-Mn AND Fe-V ALLOYS

M. Rubinstein, G. H. Stauss, and J. Dweck
Naval Research Laboratory, Washington, D. C.

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The hyperfine field distributions at both the host and the impurity nuclei in iron-rich Fe-Mn and Fe-V alloys have been examined by nuclear resonance techniques.

In this Letter we report the observation of corresponding satellites on the host and impurity nuclear resonance lines in Fe-rich alloys containing small concentrations of either Mn or V. The most striking result of this study is the observation of almost identical hyperfine spectra in the Mn and Fe nuclear resonances in the Fe-Mn alloys. This is interpreted as evidence that the changes in the hyperfine fields at nuclei near a Mn impurity arise predominantly from induced changes in the conduction-electron spin polarization (cesp). In the Fe-V alloys no simple relationship between the hyperfine field distributions is found for the Fe and V spectra. Here it appears that, in addition to perturbing the cesp, a V impurity

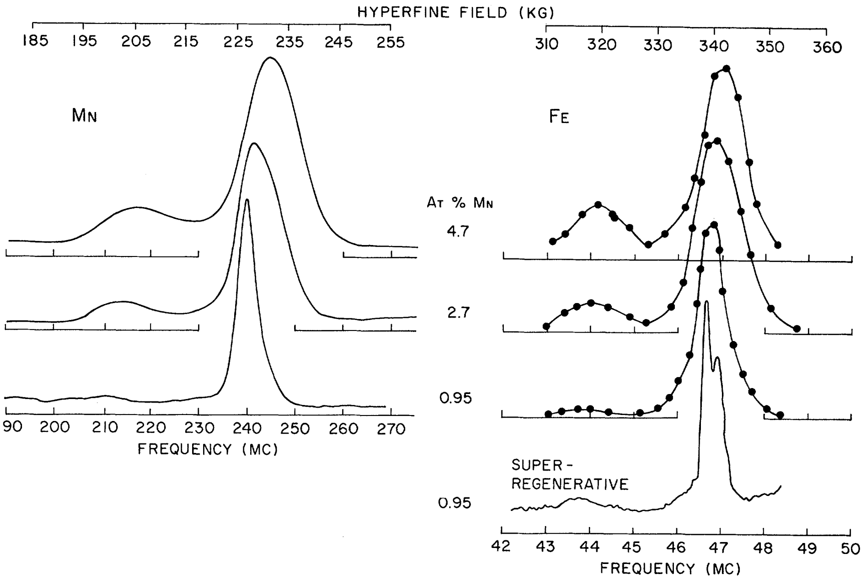

FIG. 1. ^{57}Fe (spin echo) and ^{55}Mn (marginal oscillator) nmr spectra in Fe-rich Fe-Mn alloys. Data are uncorrected for frequency dependence of signal amplitude.

also significantly changes the 3*d* magnetic moment on the Fe and V ions in its vicinity, in agreement with the diffuse neutron scattering measurements of Collins and Low.[1]

The ^{57}Fe nuclear-resonance line shape was determined by measuring the amplitude of a spin-echo signal as a function of frequency ν across the inhomogeneously broadened line.[2] A frequency-swept superregenerative oscillator was used to verify the ^{57}Fe spin-echo line shape for the samples containing the smallest concentrations of V and Mn. The increased resolution of the superregenerative oscillator allows an additional satellite line positioned at the high-frequency side of the central ^{57}Fe resonance to be detected in the 0.95% Mn-Fe alloy; the over-all agreement between the two methods is quite satisfactory. A marginal oscillator, made from a commerical grid-dip meter, was used to scan both the ^{51}V and the ^{55}Mn nuclear resonances. Both oscillators utilize fast-passage effects and phase-sensitive detection in quadrature with the applied frequency modulation to display the distribution of local hyperfine fields directly.[3]

All measurements were made at liquid-helium temperature. The spectra obtained for three different Fe-Mn alloys are shown in Fig. 1. It is apparent that all the features of the ^{57}Fe resonances are reproduced in the ^{55}Mn resonances. To emphasize the accuracy of the scaling between the two resonance line shapes we have redrawn the ^{57}Fe and the ^{55}Mn spectra for the 4.7% sample in Fig. 2. We have equalized the amplitudes of the principal maxima and adjusted the hyperfine field scales so that the positions of the satellite maxima coincide in this figure. Furthermore we have corrected for the ν^3 amplitude dependence in both lines and for the frequency dependence of the modulation amplitude across the Mn line.

A hyperfine field scaling factor which characterizes the Fe-Mn alloy system may be defined as the ratio of the hyperfine field shift of the nearest neighbor Mn satellite line (from the central ^{55}Mn resonance) to the corresponding field shift of the ^{57}Fe. From the data of

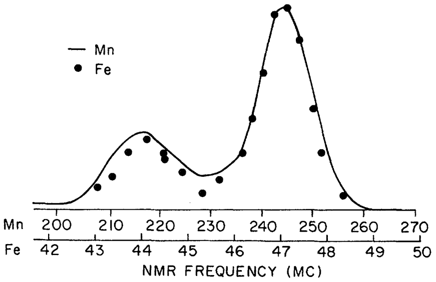

FIG. 2. Superposition of ^{55}Mn and ^{57}Fe nmr spectra for 4.7% Mn Fe-Mn alloy. Signal amplitudes of both spectra have been corrected for frequency dependence, as explained in text.

Fig. 1 or 2 we obtain $\Delta H^{\text{Mn}}/\Delta H^{\text{Fe}} = 1.26$. Since the lineshapes of the Mn and Fe resonances are determined by the (unresolved) field shifts produced by impurity neighbors other than the nearest, detailed scaling of the two spectra implies that approximately the same scaling factor also applies to the relative field shifts of these farther neighbors. (It should be noted that the scaling factor applies only to the hyperfine field shifts, and not to the value of the hyperfine fields themselves.)

A typical result for the Fe-V alloy system is shown in Fig. 3, where we have superimposed the ^{57}Fe and the ^{51}V spectra obtained from a 4.4% V alloy. Although the spectra are not dissimilar in appearance there is clearly no accurate scaling between the hyperfine field distributions of the two constituents in this alloy system. We find the scaling factor for the field shifts of the nearest-neighbor sites only to be $\Delta H^{\text{V}}/\Delta H^{\text{Fe}} = 0.57$.

We interpret these results with a model in which the Fe hyperfine-field changes are given by

$$\Delta H^{\text{Fe}}(r) \approx (8\pi/3)\mu_{\text{B}}\Delta\sigma_{4s}(r) - 1.5\times10^{5}\Delta\mu_{3d}{}^{\text{Fe}}(r). \tag{1}$$

Here $\Delta H^{\text{Fe}}(r)$ is the difference between the hyperfine field at an Fe nucleus a distance r from the impurity site and the hyperfine field at a nucleus infinitely distant. The two major contributions to $\Delta H^{\text{Fe}}(r)$ are assumed to be the change in the contact hyperfine field due to itinerant 4*s* conduction electrons and the change in the core-polarization hyperfine field from "localized" 3*d* magnetic moments on the Fe, both of which arise from the introduction of an impurity ion. The conduction-electron term is proportional to the local change of itinerant 4*s* cesp density, $\Delta\sigma_{4s}(r)$, produced by the interaction of the conduction electrons with the nearby impurity via the Ruderman-Kittel-Kasuya-Yosida mechanism.[4] The core-polarization term is proportional to the induced change in the 3*d* magnetic moment located at the Fe ion, $\Delta\mu_{3d}{}^{\text{Fe}}(r)$, resulting from incomplete charge shielding at the nearby impurity site. A constant of proportionality of -150 kOe/μ_{B} is assumed.[5]

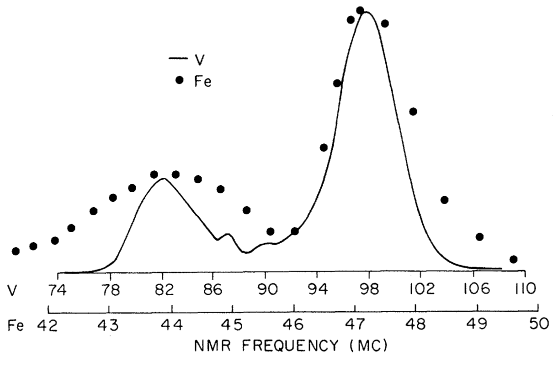

FIG. 3. Superposition of ^{51}V and ^{57}Fe nmr spectra for 4.4% V Fe-V alloy. Signal amplitudes of spectra have been corrected for frequency dependence.

The change in the hyperfine field at an impurity (Mn or V) nucleus caused by the presence of another impurity ion at a distance r is given by

$$\Delta H^{\text{imp}}(r) \approx (8\pi/3)\mu_{\text{B}}\Delta\sigma_{4s}(r) - 1.5\times10^{5}\Delta\mu_{3d}{}^{\text{imp}}(r). \tag{2}$$

For a given alloy system the same $\Delta\sigma_{4s}(r)$ is used in Eqs. (1) and (2). This should be a valid approximation since both the host and the impurities are transition elements with similar nuclear charges. However, the core-polarization term in Eq. (2) will, in general, differ from its counterpart in Eq. (1) since there is no a priori reason to assume that the induced change in the magnetic moment residing on an Fe ion will be equal to the induced change in moment on an equivalently positioned impurity ion.

The cesp contribution to $\Delta H(r)$ is always important in Fe alloys whenever the moments on the host and the impurity are dissimilar; large satellite line separations are observed in Fe alloys for which the core-polarization contribution is believed to be near zero, e.g., Al and Si.[6] Whenever the core-polarization contribution can be neglected with respect to the cesp contribution, $\Delta H^{\text{imp}}(r)/\Delta H^{\text{Fe}}(r) \approx 1$, i.e., the magnitude of the hyperfine field shifts of the satellite lines of the Fe and the impurity ion will be nearly equal. Since we observed $\Delta H^{\text{Mn}}(r)/\Delta H^{\text{Fe}}(r) = 1.26$ for all neighbors, we tentatively conclude that in Fe-Mn alloys the hyperfine-field changes induced by the Mn impurities are caused predominantly by perturbations in the conduction-electron-spin polarization.

On the other hand, for those alloys in which the core-polarization contribution is significant, we expect neither equality between the field shifts of the host and impurity satellite lines [unless $\Delta\mu^{\mathrm{Fe}}(r) = \Delta\mu^{\mathrm{imp}}(r)$] nor a detailed scaling of the two spectra [since $\Delta\sigma_{4s}(r)$ and $\Delta\mu_{3d}(r)$ arise from different physical mechanisms and are not expected to be proportional]. This appears to be the case for the Fe-V-alloy system. We conclude that a V impurity in Fe significantly alters the core-polarization field on neighboring nuclei, whereas a Mn impurity does not.

An estimate of $\Delta\mu^{\mathrm{Fe}}(r)$ on the nearest-neighbor Fe nuclei shows that these conclusions are reasonable. In the Fe-V alloys Collins and Low[1] have deduced from their neutron-scattering experiments that an Fe ion having a nearest-neighbor V ion suffers a loss of moment $(0.08\text{-}0.16)\mu_{\mathrm{B}}$. This corresponds to a field change of 12-24 kOe, which is a significant part of the total change on the nearest neighbor as measured by nuclear resonance. In the Fe-Mn alloys Collins and Low report no appreciable effect of a Mn impurity on the moment of a nearby Fe ion, which indicates that the core-polarization perturbation is considerably smaller in Fe-Mn than in Fe-V. Using the equation[7]

$$\Delta\mu^{\mathrm{Fe}} \approx (d\bar{\mu}/dc + 2.2 - \mu^{\mathrm{Mn}})/12, \tag{3}$$

where the change in average moment per added Mn ion $d\bar{\mu}/dc = 2.1\,\mu_{\mathrm{B}}$, and taking the moment residing on the Mn impurity $\mu^{\mathrm{Mn}} \approx 0.5\mu_{\mathrm{B}}$ as given by Low,[8] we obtain $\Delta\mu^{\mathrm{Fe}} \approx 0.03\,\mu_{\mathrm{B}}$ for the change in moment on a nearest neighbor Fe ion. This corresponds to a core-polarization contribution of 4.5 kOe, which is considerably smaller than the measured change of 21 kOe.

Based on the anomalous temperature dependence of the ^{55}Mn hyperfine field, Jaccarino, Walker, and Wertheim[9] have proposed that a large moment ($\sim 2\mu_{\mathrm{B}}$) resides on the Mn ion. If this hypothesis were true (and Collins and Low's measurements incorrect) the moments on the Fe and Mn atoms would be quite similar, and the scattering of conduction electrons off the Mn impurity would be expected to be small. The core-polarization contribution to $\Delta H(r)$ would then be dominant, in contrast to the conclusions reached above, and our data would then indicate that Fe and Mn atoms adjacent to a Mn impurity would suffer equal losses in moment of $\sim 0.15\mu_{\mathrm{B}}$. Equation (3) predicts $\Delta\mu^{\mathrm{Fe}} \approx -0.16\mu_{\mathrm{B}}$ when $\mu^{\mathrm{Mn}} = 2.0\mu_{\mathrm{B}}$, showing that the core-polarization field would indeed be the dominant cause of the satellite line separations should the moment on the Mn ion be large. However, because of the convincing nature of the neutron-scattering results, and also because Low has recently shown that the anomalous thermodynamic behavior could occur with a small moment on the Mn ion,[8] it seems unlikely that the Mn moment exceeds $\frac{1}{2}\mu_{\mathrm{B}}$. Unless the neutron-diffraction experiments are seriously in error we conclude that the satellite hyperfine-field spectra are determined primarily by conduction-electron perturbations in Fe-Mn.

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